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ROYAL AIRCRAFT ESTABLISHMENT

F A R N B O R O U G H, H A N T S

TECHNICAL NOTE: No. CHEM.1218

REPORT ON VISITS WITH Mr. A.G.P. VAUGHAN AND Mr. J. HARDWICK OF I.C.I. Ltd. TO U.S. FIRMS ENGAGED IN THE DEVELOPMENT OF REINFORCED PLASTIC ROCKET MOTOR BODIES

23rd NOVEMBER to 8th DECEMBER, 1953

by

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MINISTRY OF SUPPLY

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2 **ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH**

Report on Visits with Mr. A.G.P. Vaughan and Mr. J. Hardwick of Imperial Chemical Industries Ltd. to a number of U.S. Firms engaged in the Development of Reinforced Plastic Rocket Motor Bodies 23rd November to 8th December 1953 4

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RAE Ref: 3403/21/TL

SUMMARY

The development of reinforced plastic rocket motors in the United States has reached very much the same stage as it has in this country.

Motors are being helically wound with glass rovings and Epon resins which develop hoop stresses of 80,000 lb/sq.in. on a specific gravity of 2.0.

The attachment of end closures has been found the most difficult problem to overcome but a highly efficient method of scarf jointing metal sleeves to the ends of glass reinforced tubes has recently been developed and shows great promise for motors up to 10 in.dia. and 2000 lb/sq.in. internal pressure.

Glass reinforced plastics are being used for end closures, nozzles and tail pipes but there is now a tendency to switch to the asbestos/phenolic materials which are preferred in this country.

Dr. L.G. Bonner of the Allegany Ballistics Laboratory summed up the opinion of all those we met by saying there was "very considerable confidence in the future of reinforced plastics for the manufacture of rocket motors" and that the time had come to go ahead and produce an all-plastic motor, possibly in large numbers.

1. Rocket motors

I Lloyd, T
II Imperial Chemical Ind., Ltd.
III Title: Reinforced plastic rocket motor bodies...

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1 Introduction

1.1 The tour was proposed and arranged by D.D./G.W.R.D., the main objectives being as follows.

(1) For Imperial Chemical Industries' representatives to acquire sufficient knowledge of M.W. Kelloggs and Young Development Laboratories' machines and processes to enable them to build a similar machine and to produce helically reinforced plastic motor bodies at Summerfield at the earliest possible moment.

(2) To exchange views on the theoretical efficiency and economics of reinforced plastic rocket bodies.

(3) To investigate the apparent difference in approach to the problem of developing satisfactory plastic end closures for rocket tubes.

(4) To discuss the merits and demerits of helically wound tubes, especially regarding porosity and low bending properties.

(5) To investigate the properties and techniques of using Epon and any other promising resins.

As this report is written primarily for those actually engaged in making reinforced plastic rocket motors it is full of detail and therefore too long to be read by those not actually engaged in the art.

An attempt has therefore been made to mention every aspect of interest under General Conclusions (Section 6) and to arrange the list of contents to facilitate reference to the main report for details of any particular subject.

1.2 Itinerary

Date	Firm or Organisation	Main Interest
23rd Nov.'53	I.C.I. Office, 5th Avenue, New York	Arranging final detail of programme
24th Nov.'53	M.W. Kellogg Jersey City, N.J.	General introduction and detailed examination of tube winding machines
25th Nov.'53	M.W. Kellogg	Plastic tube winding machine and manufacturing process
26th Nov.'53	Thanksgiving Day	The sights of New York
27th Nov.'53	M.W. Kellogg	End closures and hydraulic testing
30th Nov.'53	Young Development Laboratories, Princeton	a.m. General discussion on plastic tubes p.m. Detailed examination of winding machines
1st Dec. '53	B.J.S.M. Washington	General discussion with Dr. C.G. Lawson.

2nd Dec. '53	Allegany Ballistics Laboratory, Cumberland	Meeting with Dr. L.G. Bonner (Tech. Director) and tour round Establishment
3rd Dec. '53	Allegany Ballistics Laboratory, Cumberland	Discussion on plastic tubes, end closures and venturis. Witnessed firing trials
*4th Dec. '53	A.B.L. Cumberland	General discussions amongst all interested parties
*7th Dec. '53	Goodyear Aircraft Corpn. Akron, Ohio	Tour round factory and discussion on cloth and roving composite tubes and end closures. Also braided tubes with nozzles.

2 Visit to M.W. Kellogg Co.

2.1 Survey of work being done

Mr. Dexter Miller explained that the factory, which employed about 800 men, was mainly engaged in the manufacture of pressure vessels, high pressure pipework, condensers etc. in steel, but that 25% to 30% of their production was in the form of Rocket Motor Cases from 12 in. to 30 in. dia. under U.S. Navy contract.

The Special Projects Department of which Mr. Miller was in charge is relatively small and is mainly engaged in developing a new method of welding steel tubes with little or no internal bead and winding solid fuel rocket motor cases with glass rovings and Epon Resins.

The effort on reinforced plastic work appeared to comprise two staff and three to four shop workers who were engaged in making helically wound tubes and testing their bending, torsional and compressive strength. They were particularly interested in these properties because the projects on which they were engaged were all tandem boosted.

2.2 Tube winding machines

Two machines were in use, one being capable of winding 6 in. dia. tubes up to 2 ft. long and the other 16 in. dia. up to about 10 ft. long, the latter (Fig.1) being arranged to lay on 8 rovings of 10 ends each in a ribbon 5/8 in. wide. The carriage is operated by a master pin attached to an endless chain and the comb and laying-on tongue (Fig.2), which is covered with Teflon sheet, are reciprocated automatically at the end of each traverse so that the rovings leave the comb at the same angle as the angle of helix being wound on the tube. A detailed description of the machine is being prepared by I.C.I. representatives which will include a number of photographs taken during our visit. By very precise adjustment of gearing and size of chain sprockets the laying-on of rovings can be done so accurately that the whole mandrel on which the tube is wound is covered by one layer of rovings before the pattern repeats itself.

The collapsible mandrel used during our visit was made of timber, but a metal one is under construction because it has been found impossible to hold diameter tolerances on the wooden one.

The mandrel revolves at 45 r.p.m. and an 8 in. dia. tube 5 ft. long by 0.20 in. wall thickness can be wound in 2½ hours when eight ten-end rovings are being laid simultaneously.

* Party accompanied by Dr. C.G. Lawson of B.J.S.M. Washington.

2.3 Tube winding process

The sections of the mandrel are coated with raw linseed oil and assembled in the machine between two hemispherical end caps of aluminium. The barrel portion is then wrapped in aluminium foil and the whole assembly sprayed with a silicone release agent XC. 130 made by Dow Cornings. Eight cheeses each carrying 10 ends of 200/150 untwisted glass rovings are weighed and placed on rotating spindles mounted on the carriage of the machine. The spindles are mounted nearly vertically and have flanges at their bottom ends which bear on friction brake pads so arranged that laying-on tension remains more or less constant at 0.5 lb. per roving as the glass is removed from the cheese. Each roving is then passed between a pair of horizontal guide bars to restrict its vertical travel, through its appropriate space on the oscillating comb and tongue and attached to the mandrel.

The machine is then started and the laying-on tongue adjusted relative to the traversing carriage so that the windings terminate at relatively the same point on each end of the mandrel. The angle of oscillation of the comb and tongue is next adjusted to suit the helical angle being wound and their relative position to the mandrel set to spread the rovings into a 5/8 in. wide ribbon.

Meanwhile a number of 400 gm batches of Epon Resins Shell Nos. 828 and 562 are well mixed together in proportion 65/35 by weight respectively. 8 parts by weight of total resin weight of Shell curing agent A are stirred into each batch shortly before it is required.

As winding proceeds resin is poured on top of the mandrel and spread by a hand operated squeegee having a Teflon blade 8 in. wide by 1 in. deep which also removes any surplus. Applications of resin are made whenever the tube "looks white", any excess dropping onto sheets of brown paper, previously weighed and placed under the mandrel. It is said that resin contents can be controlled accurately by this technique.

A bank of infra-red lamps is suspended over the winding machine and is switched on at intervals during the last hour of winding to keep down the viscosity of the resin and thus assist consolidation of the winding. Control of infra-red heating is governed by the 'feel' of the resin on the squeegee; as soon as it begins to drag the heating is switched off.

After winding is completed the mandrel is kept rotating and the infra-red heating intensified until the resin is sufficiently cured to allow the tube to be cut to length with a hacksaw blade.

The mandrel is then removed and the tube cured in an air circulating oven at 200°F (93°C) for four hours.

The gear for laying on additional axial rovings consists of two pairs of wooden discs, of slightly larger diameter than the finished diameter of the tube being wound, and each carrying 150 equally spaced steel pegs round its periphery. Each pair of discs is fitted with three lightly spring-loaded plungers which are located in fittings on the aluminium end caps of the mandrel before it is inserted in the machine. At various stages of the wind the mandrel is stopped and one roving is threaded through a special needle with which it is laboriously passed round all 600 pegs. When the helical winding is resumed the axial rovings are tensioned by being pulled in to the tube walls, thus compressing the springs on the peg bearing discs.

2.4 End closures and nozzles

M.W. Kelloggs' early end closures were very similar to those first used at the R.A.E. but it was soon found that winding glass over metal or plastic end closures or annular inserts was unsatisfactory owing to the large strain movement of the walls under internal pressure.

The next stage was to machine the outside ends of the glass tubes parallel and to glue over them steel sleeves which carried grooves for snap rings or other methods of securing the actual end closure. This method was also found unsatisfactory as it proved impossible to make reliable glued joints and trouble was experienced from stress concentrations in the glass walls at the inner ends of the steel sleeves.

The method now being used consists of machining the outside ends of glass tubes to a taper of between 5^{o} and 7^{o} (for a wall thickness of 0.200 in.) with a finish so rough as to resemble a fine screw thread and to glue on to them steel sleeves with a matching internal taper of equally rough finish. Glass and metal surfaces are degreased by wiping with acetone and a liberal coating of Shell Epon VI adhesive applied to glass and steel. After an open assembly time, which did not appear to be considered critical, the steel ends were pushed home by hand with a screwing motion and the assembly cured at 200^{o}F for four hours.

End fittings of this type on 6 in. dia. tubes with 0.20 in. wall thickness usually blow off at around 3000 p.s.i. internal pressure but they are not yet reliable. During our visit a 6 in. dia. tube with two of these ends was tested hydraulically to 4080 p.s.i., the highest figure reached to date giving a shear load of 6000 lb. per inch of circumference, when one end blew off taking some thin layers of glass laminate with it. It is realised that it may not prove possible to scale up these scarfed joints or to make the gluing sufficiently reliable, and other methods of securing metal fittings outside glass tubes, with wall thickness built up on the outside, are being investigated. These include swaging, which is not thought practicable by their workshops, and using segmented rings inside a retaining sleeve, but all have the disadvantage of increasing the external diameter and weight of a motor to an objectionable extent.

Little work has been done on plastic end closures and there seemed to have been no interest in plastic nozzles until our visit.

2.5 Resins

Polyester resins were used in the first instance but a mixture by weight of 65/35 Shell Epon Resin Nos. 828 and 562 with 8 parts by weight of Shell curing agent 'A' is now used as the standard laminating resin for all tubes. It has excellent glass wetting properties, a shrinkage of only 2% on setting compared with 8% for polyesters and it is said that tubes impregnated with it are less porous than any others tested to date: it also gives the best figures in tension and bending, and it was noticed that the interlaminar resistance to stripping by hand was considerably superior to that in laminates made with polyester resins at the R.A.E.

Some small test tubes were being wound using a high temperature resistant Shell resin but strength test results have not been encouraging even at room temperature. It requires a two stage cure, one hour at 300^{o}F (149^{o}C) plus one hour at 400^{o}F (204^{o}C) and is dark brown in colour after cure.

H.H. Robertson, who supplied the polyester resins for M.W. Kelloggs' early work, say they now have a polyester which is superior in all respects to Epons and are to supply free samples for comparative test.

When enquiries were made about pretreatment of glass, we were informed that it was Kellogg practice to give their glass suppliers full details of the manufacturing technique and resins to be used and leave the choice of treatment to them. It seemed that chrome finish was probably being supplied.

2.6 Mechanical testing

Hydraulic testing is carried out in a large electrically lit concrete lined pit covered by heavy chequer plating in which a number of guarded plexiglas inspection windows are mounted. All testing is done with water which is supplied from an air driven pump whose maximum delivery pressure is 5000 lb./sq.in.

A rig for testing tubes in bending, torsion and compression has been in use for some time[1] and a series of tubes is now being wound with additional axially laid rovings for a further series of tests. It is thought that as much as 30% additional glass may have to be used in this way if the optimum pressure vessel helical winding angle of 55° is used.

A programme of tests under which tubes will be subjected to combined loads simultaneously is contemplated in which strain gauges will be used extensively. Contrary to our experience at R.A.E. these are said to give reliable results but special strain gauges are used, made by Baldwin, Lima and Hamilton of New York, having 1% and 3% strain characteristics; the latter are very expensive.

2.7 Optimum angle for helical winding

All tubes are wound at a helical angle of 55° with the axis of the tube and Kelloggs find that failure under hydraulic test of tubes wound with this angle have been very nearly 50% axial and 50% hoop, thus indicating theory and practice to be closely in line on this important aspect.

2.8 Economics

Mr. Miller was rather indefinite about production costs but it appeared that polyester resins cost about 50 ¢ per lb., Epons around $ 1.70 per lb. and 10 end 150 glass rovings 50 ¢ per lb.

He estimated the cost of winding 8 in. dia. tubes with 0.20. in. wall thickness by the method now standardised at $ 3.0 per foot or 80 ¢ per lb.; the labour cost has obviously not been included but it is interesting to record that the cost of raw materials in U.K. to make an identical tube using the much cheaper polyester resin is about 25/- per foot or 6/3d. per lb.

2.9 Final discussion and conclusions

A final meeting was held on the afternoon of 27th November at which the design of plastic boost motors of the tandem type was discussed in general terms. Kelloggs' representatives considered that the nozzle end should be removable and that the charge should be held against obturating seals at this end by steel or plastic springs at the head. They thought that it was going to be difficult to meet the bending

requirement without spoiling the efficiency of the helically wound tube as a pressure vessel and realised that the end closure problem was probably still a long way from being solved.

When asked their views on the very considerable strains which were bound to take place with glass reinforced materials, Mr. Miller pointed out that provided the bending problem was solved they were not worried about nozzle alignment and that if large diameter metal sleeves could be reliably scarf jointed to the glass tube no special attachment or separation problems need be anticipated.

With the departure to another job of Mr. Bob Gardner on the last day of our visit, Kelloggs now have nobody on their staff with any great experience in reinforced plastics and one therefore wonders whether they intend to continue their work in this sphere or merely to conclude the two ad hoc research jobs they have in hand.

3 Visit to Young Development Laboratories

3.1 General survey of work being done

Mr. Young explained that his firm was working on Naval Ordnance Contracts sponsored by the Allegany Ballistics Laboratory for design and material evaluation of glass reinforced plastics, particularly for the manufacture of rocket motor cases.

They had manufactured a number of 16 in. dia. all plastic Terrier boost motors (Fig.3) in collaboration with the Glenn L. Martin Co. of Baltimore and most of these had been hydraulic tested to 1,800 p.s.i. and fired at 1,200 p.s.i. They were designed specifically for secret fragmentation trials, were very heavy having 5/16 in. thick walls, and did not incorporate the latest ideas on design of end closures, nozzles, etc., but every component, including the grain hold back springs, had been made in reinforced plastics and they had proved that motor cases of this size could be made by winding glass rovings at the correct helical angle.

In addition to Government work, Mr. Young is producing roving wound pipework for a commercial firm for which they have developed an efficient means of jointing and are trying out methods of manufacturing bends etc.

3.2 Tube winding machines

Two machines very similar to the larger one at M.W. Kelloggs[2] were in use and a third was under construction at the time of our visit. Young passes his endless chain round four sprockets arranged in pairs at each end of the machine so that the chain travels for a short distance in a direction about 45° to the vertical, thus altering the "dwell" period of the carriage at the end of each traverse. His method of oscillating the comb and laying-on tongue is also different and more flexible than the earlier Kellogg machine and he has introduced an infinitely variable hydraulic drive between his driving motor and gear box. The machine under construction employs a different method of controlling the "dwell" at the end of the carriage traverse and yet another method of oscillating the comb and laying-on tongue. All these refinements are designed to maintain extreme accuracy of helical wind under all conditions, which is considered essential for accurate control of glass content.

The method of tensioning the rovings during winding is exactly the same as on the Kellogg machine and Mr. Young stated that tension should

vary from 1 to 3 lb. on 8 to 12 end rovings or about 25% of their breaking load. For tubes of normal wall thickness precise control was not important except in so far as it affected resin content.

Collapsible mandrels were not used for tubes with one open end; silicone mould release compound (Dow Cornings XC 130) was sprayed on the mandrel and removal effected hydraulically. Woods metal had been found unsatisfactory as a mandrel as generally speaking it did not run out cleanly and Mr. Young showed great interest in the R.A.E. method of winding on to thin pre-cured Durestos formers which are left inside and act as efficient heat insulators.

The mandrel used for 16 in. dia. boost motor cases was rolled from steel plate, welded, stress relieved and machined to wall thickness of 1/16 in. It weighed 1,500 lb.

Heated mandrels are used quite frequently because in general they help to keep resin viscosity on the mandrel low and pot life long. A case was quoted where a tube which took fifteen minutes to wind was ready to rub down at the finish of the winding. External heating by infra-red lamps was obviously no substitute.

3.3 Tube winding process

During our visit to the winding shop a length of 2 in. dia. pipe was being wound on a heated mandrel using Epon resin No. 828 and special curing agent D. Four rovings of 8 ends each were being wound on and the resin was obviously much more viscious than the usual mixture of Nos. 828 and 562. The Teflon squeegee was not used at all until after winding had been completed, but it was employed to give the tube an extremely good external finish while the resin was in process of gelling.

Mr. Young explained that the amount of rovings wound on at a time depended on the size of the tube, the maximum they had achieved so far was 16 cheeses of 8 ends each. He outlined an idea he had, which tended toward the braiding technique, by which the amount of glass laid on could be increased very greatly but it is very questionable if the accuracy of the wind could be maintained.

When winding a tube with 1 in. thick wall it was found to be loose on the mandrel after gelling and this seemed another instance when close control of mandrel temperature may prove advantageous.

Excess resin must always be present on the mandrel but the content of the final tube is kept as near 25% as possible by controlling the viscosity of the resin by heating the mandrel up to temperatures as high as 200°F, and to a lesser extent by the winding tension on the rovings. A resin content of 20% tends to make tubes porous even when using the 65/35 mixture of Nos. 828 and 562 Epon resins.

3.4 End closures and nozzles

Early end closures were of the wound-in type and suffered from the usual troubles due to the low modulus of glass. The sketch Fig.3 shows the head and nozzle closures used on the 16 in. dia. Terrier Boosters referred to earlier.

The glued scarf joint seen at M.W. Kellogg is used but the sleeve is of aluminium which, in the words of Mr. Young "works well with glass laminates". Obviously the stress concentration in the glass at the end of the sleeve must be less and it is said that Epon Adhesive No.VI gives

an excellent stick between Epon impregnated glass and aluminium if the aluminium is given a chromic acid dip.

Mr. Young agreed that a study should be made of developing thread forms suitable for glass laminates and other reinforced plastics and said he had begun a material evaluation for this purpose. He had achieved inter-laminar shear figures as high as 5,000 lb/sq.in. experimentally although he proposed to use a figure of 3,000 lb/sq.in. for design purposes.

It was agreed that end closures and nozzles were likely to be a very profitable field for reinforced plastics. He had done little work on these as he had no press tools but the 16 in. dia. Terrier boost motors had glass reinforced head end closures and nozzles with graphite inserts. He had done some work and written a report for A.B.L. on filament wound nozzles.

3.5 Resins and glass

The Shell Chemical Corporation are extremely co-operative and a mixture of 65/35 of their Epons Nos. 828 and 562 is the best laminating resin for roving wound tubes; they wet glass very well and have high mechanical properties. They have recently produced a new curing agent D for these resins which is entirely compatible with nitroglycerine. Epon resins are more toxic than polyesters and some people are extremely allergic to them; their vapours are heavier than air and there is no fire risk. It is found that the curing cycle can be varied from 4 hours at 200°F (93°C) to 1½ hours at 400°F (204°C) without adverse effects.

Epon VI adhesive is giving excellent results especially on the scarf joint end closures; it's pot life after addition of hardener is shorter than that of the laminating resins.

Tubes impregnated with polyester resin have given hoop failing stresses of 80,000 to 90,000 lb. per sq.in., but the failure looks very granular and tubes were so porous they could not be tested without a flexible liner.

Araldite has been tried as a laminating resin but its pot life is short and its exothermic reactions on curing too high.

The glass rovings used are supplied by Owens Corning under the designation E.C.G. Low Alkali Pyrex type 150's. Finer filaments down to 450's have been wound but with no increase in ultimate strengths of tube, probably because of damage to filaments during winding. Finishing processes which give the best ultimate hoop strengths do not give the best porosity and inter-laminar shear strength results and vice versa. Garan finishes such as Cornings 120PX are kind to the fibre during cleaning but do not allow proper wetting and are therefore good for ultimate hoop strength, whereas chrome treatment 114 allows good wetting but the heat precleaning process associated with it damages the fibres. It is a pity that the solvents used in this process prevent it being used at the bushings or filament drawing stage.

The glass manufacturers have done a great deal of work on the development of glass treatments for polyester resins but seem rather reluctant to do it all over again for Epons which certainly show less sensitivity in this respect.

3.6 Mechanical testing

Mechanical testing has been mainly confined to bursting by internal hydraulic pressure and for this purpose tubes are lined with an open weave Nylon cloth impregnated with Thiokol which expands with the tube under test and remains non-porous. If the Thiokol is not fully cured when the tube is wound on to it, it tends to co-polymerise with the Epon resin, so forming a good bond.

Four Thiokol lined 6 in. dia. test specimens wound with Garan 120PX treated rovings, the standard 65/35 mixture of Epon 828 and 562 resins and helical angle of $54^{o}45'$, had yielded an average ultimate hoop stress of 101,000 lb/sq.in. Tubes wound with chrome treated glass, but otherwise exactly similar, are virtually non-porous at hoop stresses up to 60,000 lb/sq.in. provided the resin content is not lower than 25%, their ultimate hoop stress being about 80,000 lb/sq.in., but it is quite impossible to wind non-porous tubes with rovings if polyester resins are used.

A 6 in. dia. tube with 0.1 in. dia. wall and Thiokol impregnated nylon sealing liner has been taken to 75% of its porosity failing load 100 times without sign of failure, the hoop stress at this repeated load being 60,000 lb/sq.in.

When asked about the strength in bending of helically wound tubes Mr. Young stated that he had done no serious tests but had suspended a 20 ft. length of 2 in. dia. pipe with 0.05 in. wall thickness as a cantilever and found that the deflection was quite acceptable, the bending modulus being about 2×10^{6} lb/sq.in. He had subjected tubes to controlled blows on their outer surfaces and found that when the affected area became lighter in colour, indicating internal delamination, it became very porous but that the ultimate hoop strength was hardly affected.

Some small gas bottles had been manufactured which had shown a diffusion rate of 1 lb. per sq.in. per hour at 500 lb/sq.in. working pressure. One of these had been jettisoned at 50,000 ft. and was picked up undamaged after falling on sandy ground.

3.7 Optimum angle for helical winding

Mr. Young nearly always used an angle of $54^{o}45'$ with the axis of the tube and he had found by the use of strain gauges that a departure of only 3^{o} from this optimum "resulted in a virtually infinite modulus in one direction at the expense of that in the other".

3.8 Conclusion

Mr. Young probably knows more about winding glass reinforced plastic tubes than anybody in the U.S. and he has designed and built most ingenious machines for this purpose which control the helical angle of wind with remarkable accuracy.

On arrival at Young Development Laboratories each member of the party was asked to sign the following agreement:-

AGREEMENT

It is understood and agreed by the undersigned that certain designs, processes and methods observed on this date in the establishment of Young Development Laboratories, Inc. are regarded as proprietary.

It is further agreed that none of this information will be used or disclosed to others without prearranged permission.

YOUNG DEVELOPMENT LABORATORIES, INC.

Date ______________________________

No specific items were referred to as being considered proprietary and apart from some novel features of the machines, which there was no time to absorb, and the use of a heated mandrel, we neither saw nor were told anything particularly novel.

4 Visit to Allegany Ballistics Laboratory

4.1 General survey of work being done

Dr. L.G. Bonner, Technical Director, explained that the Establishment was administered by the U.S. Naval Ordnance branch and staffed by the Hercules Powder Company. They were the Rocket Design Authority for the Bureau of Ordnance and their terms of reference were to develop materials and evolve design criteria for all things pertaining to rocket motors in all promising materials.

They were the sponsors for all work being done by commercial firms for the Bureau of Ordnance and it was understood that they were spending about $ 150,000 a year on the development of reinforced plastic materials for rocket motors and their components.

4.2 Winding machines and processes

No winding machines are installed but the Establishment keeps in close touch with M.W. Kellogg, Young Development Laboratories, Goodyear Aircraft Corpn., Universal Moulded Products and Fairchild Engine and Airplane Corpn. who are all doing sponsored work on tube winding. It is therefore in a position to evaluate the merits of the various machines and processes being used.

M.W. Kellogg and Young Development Laboratories had concentrated on helically wound tubes using glass rovings and Epon resins. As pressure vessels they were most efficient but their performance at elevated temperatures would not be known until February, 1954, when Mr. Young hoped to conclude a programme of tests on this aspect.

The Goodyear Aircraft Corpn. had developed a composite method of construction using 2 to 1 unidirectional glass cloth axially and circumferentially wound glass rovings, Selectron polyester resin being used to impregnate the whole.

Universal Moulded Products Corpn. have wound some tubes in square weave and also in 2 to 1 glass cloth. They used sleeve type end closures with parallel glued joints which gave much trouble and it was found that when square weave and 2 to 1 cloth were used together delamination often occurred at the interface.

No details of the work being done by the Fairchild Engine and Aeroplane Corpn. were available but it will be seen from the titles of the last two reports listed in Appendix II that they are engaged in the development of a plastic J.A.T.O. motor.

4.3 End closures, nozzles and tail pipes

An evaluation of plastic end closures with and without integral nozzles was proceeding. High and low pressure mouldings using glass and asbestos cloth, mat and flock with polyester, Epon and phenolic resins were being used and it was felt that this was a particularly suitable application for reinforced plastics, as considerable economies in weight and cost could be achieved. The development of an efficient and easily mouldable screw thread configuration would make this application even more attractive and it was suggested that heli-coil thread inserts, much used with soft alloys, might well find a useful application here.

The glued scarf joint with light alloy end sleeves was considered most promising but the maximum diameter on which it had been used was $8\frac{1}{4}$ in. and it might well prove impossible to make gluing reliable enough for such a vital purpose. It had not been subjected to shock loading, nor had cycling or humidity tests been carried out, although it appeared that strengths were slighly increased at low temperatures.

The design of metal nozzles is based on heat requirements and therefore low weight medium strength materials with good heat insulating properties and resistance to erosion are obviously attractive, particularly if they lend themselves to cheap methods of manufacture.

Nozzles have been wound integral with tubes and as separate units using glass yarn roving and tape with polyester and Epon resins. Firing trials show that erosion of approach and exit cone surfaces is acceptable for burning times up to four seconds but that carbon or steel inserts are necessary in the throat.

The Cincinatti Testing Laboratory are to mould 11 in. long nozzles wt with 2.4 in. dia. throats in chopped glass rovings and phenolic resin by the injection process at 4,000 lb/sq.in. Their first effort was seen and showed that the mould cavity had only partially filled before cure began and it was suggested that displacement moulding using asbestos fibres in place of glass would produce better results. A 4 in. compressor blade moulded by the same firm with glass cloth skin and chopped roving core was seen. It looked weak at the root but had not been tested.

The High Pressure Moulding Corpn. and Cincinatti Testing Laboratories have been asked to mould asbestos/phenolic tail pipes which are considered very promising because they combine low cost and low weight with good heat insulating properties.

We saw a tail pipe, $1\frac{3}{8}$ in. bore by $\frac{1}{2}$ in. wall, manufactured from asbestos flock by the Bristol Aeroplane Co., fired on a Type 1 Terrier sustainer, under subsonic conditions. It disintegrated after 6 secs. at an estimated hoop stress of 1,600 lb/sq.in. and A.B.L. were warned that RA.51 flock without reinforcement of some kind was quite unsuitable for this purpose.

4.4 Economics and efficiency

Forty rocket motor cases 8 in. dia. by 30 in. long had been ordered in S.A.E.4130 steel (79 ton yield) with 0.042 in. wall thickness for evaluation against cases of the same diameter and length but with

0.20 in. wall thickness made by Goodyear Aircraft Corpn. by their composite cloth and roving technique. The steel motors weighed 37 lb. each complete against $24\frac{1}{2}$ lb. for the glass and, largely because of the small number ordered the price of the steel cases had worked out at nearly $ 800 each, or about $ 20.0 per lb. The cost of the Goodyear motors is not yet available but it is not expected to be more than $ 2.0 per lb. On the other hand A.B.L. had been quoted a price, which worked out at $ 1.30 per lb, for $8\frac{1}{2}$" dia. motors made from deep drawn steel tube provided production rate was not less than 3,000 per month.

The overall Specific Impulses of the steel and glass motors with 60 lb. multi-perforated charges worked out at 137 and 145 respectively.

It was thought that braided roving tubes with integral nozzles could be made for considerably less than $ 2 per lb. but that they would be less efficient though quite suitable for J.A.T.O. requirements.

4.5 Low density anti-peak plugs

Taylos and Snark boost motors of 457,000 and 530,000 lb. sec. total impulse respectively and burning time of 4 secs. were seen fired successfully and provided most impressive spectacles. Both had low density anti-peaking plugs made of Dow Chemical polystyrene foam having a density of less than 2 lb. per cub. ft., glued into their nozzles. The plugs were truncated cones cut from $2\frac{1}{2}$" thick slab of "Styrofoam" and glued in the nozzle with Armstrongs A2 reactive adhesive which does not attack the foam. When the internal pressure reaches 18 lb/sq.in. the foam shears in itself close to the glue line and blows away in small pieces, fragmentation being assisted if the inner surface of the plug is scored before insertion.

4.6 Insulating coatings

Considerable work is being done with the object of improving internal heat insulating coatings as it was thought that light alloy motors and nozzles might well come into their own if this were achieved.

"Flame Master" was used at first but was discarded because grains tended to stick to it through interchange of plasticisers. "Pyrolock" water-based composition is now sprayed on and gives good results. "Sherwin Williams" is the best insulating material but it is too brittle and Durestos type liners have been given up owing to the difficulty of inserting and securing them.

A very clean looking light alloy motor with integral nozzle arrived for firing trials on the last day of our visit. It was manufactured by the Goodyear Aircraft Corpn. and was lined with a new insulating coating, developed by Sherwin Williams, which was built up to a thickness of 0.035 in. at the nozzle.

4.7 Centrifuge

The centrifuge consists of a centrally pivotted 60 ft. fabricated steel beam which can be rotated at speeds up to 80 r.p.m. in a concrete lined pit situated close to the main firing bed. The beam is rotated by a 500 h.p. diesel engine through a hydraulic drive and it can carry loads up to 5,000 lb. at a radius of 20 ft. and lesser loads out to 30 ft. radius.

Motors are usually mounted radially for test but they can be fired tangentially if a reaction plate is mounted behind the nozzle.

4.8 Final discussion

On the last day of our visit the party was invited to attend a meeting at which Dr. Bonner, Mr. Winer and Mr. Gottschall of A.B.L., Dr. Wise of the Bureau of Ordnance and Dr. Lawson of B.J.S.M. were present.

Mr. Winer gave an overall picture of the work being done and said that A.B.L. were convinced that reinforced plastics had an important part to play in the development and production of rocket motors both from the technical and economic points of view.

He did not think that the comparatively large strains associated with glass structures need be a deterrent and suggested that they might even be made use of for separation of wrap-round boost motors.

Glass-wound motors had been stored full and empty for more than one year with satisfactory results; they were easy to handle and were not vulnerable to denting.

End closures were discussed at length and considerable interest was shown in the R.A.E. reversed dish type which flattens under load and follows out the tube wall as it strains. The extra length of tube wall necessary to take the shear loads behind the snap ring groove was not considered a drawback because a round end is inconvenient for attachments.

Insufficient data were available to say whether the head or nozzle end of a motor should be detachable but if it proved practical to wind integral nozzles their throat diameters would have to be varied by fitting easily interchangeable steel or carbon inserts. Grain hold back at the nozzle end of sustainers was not thought practicable as back-holding may be subject to -8G at separation of boost.

The first case of Durestos R.A.1 felts to arrive in U.S. was awaiting Customs clearance at Cincinatti at the time of our visit. It was to be used for the manufacture of end closures, nozzles, tail pipes etc. and A.B.L. were advised to store it in a refrigerator.

It was stated that if tail pipes have a length/diameter ratio of over 10, supersonic speed may be reduced to subsonic by high shock waves. Losses in short tubes were of the order of 2% to 3%.

A full-scale test of one of the 16 in. dia. frangible boost motors, made by Young Development Laboratories, had been carried out in October, 1953. The results were promising as the largest fragment left after destruction was no bigger than a man's hand.

Dr. Bonner said that A.B.L. had "very considerable confidence" in reinforced plastics and thought the time had come to set up some standards and go ahead with the manufacture of a complete motor, possibly in large numbers. The situation was so fluid and there were so many possible improvements just round the corner, that there was a temptation to delay, but this must be resisted.

5 Visit to the Goodyear Aircraft Corpn.

5.1 Introduction

Prompted by the idea of using non-strategic materials the Goodyear Aircraft Corpn. started to develop a reinforced plastic motor unit in 1949 when there was no previous work to which they could refer.

Their first tubes were wound in square weave cloth and polyester resin and end closures were moulded in the same materials on wooden formers, the skirts of these units being wound in with the tube walls. The tube walls at the nozzle end were thickened up to take the bearing load of plain shear pins which secured a combined end closure and nozzle, again made of glass cloth and polyester resin and having a steel insert at the throat. Six motors 8 in. dia. by 50 in. long were made by this process, the cloth being wound on at a speed of 220 ft. per min. All were tested hydraulically and fired successfully but their efficiency was naturally low.

They now had a contract sponsored by the A.B.L. to develop economical methods of producing reinforced plastic motors with efficiencies comparable with those made from steel or other materials. The raw materials cost per lb. at $ 1.80 to 2.10 for woven cloth, 40 ¢ for roving and 50 ¢ for polyester resin were comparatively high but it was hoped that manufacturing costs could be reduced sufficiently to offset these.

5.2 Tube winding machines

The machine used for convolute winding of cloth is a typical paper rolling machine with a resin bath and a pair of squeeze rollers for removing excess resin from the cloth before it is wound on the mandrel. It is capable of winding tubes up to 10 in. dia. by 10 ft. long but it was not seen in operation.

The machine used for winding on roving circumferentially is similar to the Young machines but the endless chain runs on horizontally mounted sprockets, and its master pin engages in a horizontal cam plate, on the underside of the carriage, which is designed to prevent dwell and consequent gradual build up of wall thickness at the ends of the tubes. Details such as roving tensioners and guides were not seen but it was said that $2\frac{1}{2}$ lb. tension on 20 end 150's roving was considered satisfactory and as the helix angle is very large no complicated guiding arrangements are necessary.

The Braiding machine used by Goodyear belongs to a firm of fire hose manufacturers in Akron and was not seen. It was designed and manufactured during the war for making braided tubes up to 8 in. dia. in steel wire which were used in mines for breaking out coal hydraulically. The deck has 96 carriers each of which carries one spool of 60 end 150's roving and it is estimated that the cost of a similar machine to manufacture tubes up to 16 in. dia. would be $ 80,000.

5.3 Tube making processes

(a) Composite cloth and roving technique

Seven plies of 2/1 unidirectional 0.009 in. thick satin weave cloth are wound on to a mandrel after passing through a bath of Selectron 5003 polyester resin and a pair of squeeze rolls by which resin content is controlled. The final wall thickness is 0.07 in., the unidirectional properties of the cloth being employed axially.

After curing on the mandrel four strands of 20 end 150's roving are wound on simultaneously at a very fine pitch in the circumferential winding machine which revolves the mandrel at 110 r.p.m. Selectron 5003 resin is applied by brush during winding and the total wall thickness is built up to 0.200 in.

The whole tube is then fully cured on the mandrel, cut to length and its ends machined externally to a taper of 2^{o}. It is said that glass resin ratios of 80/20 can be regularly attained by this process.

(b) Braiding technique

Only three 4 in. dia. tubes had been wound by the braiding process at the time of our visit. The first was not a success because the 60 end 150's rovings were loose on the mandrel because of insufficient tension and because impregnation with resin was not carried out until the whole braiding process was complete; both these mistakes resulted in a tube with a 50/50 glass/resin ratio and poor mechanical properties.

The second and third tubes had integral braided nozzles, were made with increased roving tension and were impregnated with resin between each pass through the braiding machine. No particular care was taken to braid at the optimum helical angle for pressure vessels but a much better glass/resin ratio was achieved and a hoop stress of 50,000 lb/sq.in. reached. It is thought that better results can be obtained as experience in braiding is gained.

5.4 End closures and nozzles

Early end closures were made as described in 5.1 above, but experience with shear pins showed that steel inserts were necessary in the thickened up tube walls at the removable end and that an unacceptably high standard of accuracy was necessary in their manufacture.

The glued scarf joint method of end closure attachment was much liked as it gave the tube smooth internal and external walls. It is used on composite and braided tubes and the writer gained the impression that Goodyears were the originators of the idea. They have done considerable experiemental work to determine the best form of scarf joint and details of some of this will be found in Appendix I.

It is interesting to note from this appendix that scarfed glass to aluminium lap joints using Epon No.VI adhesive tested in a tensile machine seldom yield more than 2,000 lb. shear per inch width, whereas exactly comparable joints develop 4,500 lb. and on one occasion 6,000 lb. per inch of circumference in pressure vessels, provided the glass laminate is inside the metal. Failure of a good plastic to metal glued joint invariably occurs in the plastic close to the glue line due no doubt to delamination caused by the tensile component of the shear stress, and it seems likely that the internal pressure in the tube form of this joint may prevent this delamination occurring until greatly increased shear loads are reached.

Light alloy sleeves thus glued to tubes have internal grooves turned in them to accommodate light alloy segmented retaining rings which are bolted to the end closures after insertion. A.B.L. do not like spring circlips for this purpose because the end closure cannot help the circlips to resist their tendency to be turned over in their groove.

Head end closures are moulded in square weave glass cloth and polyester resin at 800 lb/sq.in. and have light alloy threaded sleeves in their centres for the reception of igniter bodies.

Nozzle end closures are wound complete in polyester impregnated glass tape and have carbon or steel throat inserts.

Light alloy rings, with a number of tapped holes round their sides are glued to the outer surfaces of both types of end closure thus distributing any concentrated crushing loads on the end closures and providing the means of securing the segmented retaining rings to them.

5.5 Mechanical testing

Only internal hydraulic tests had been carried out to date and for these it was generally necessary to line tubes with Neoprene; although the porosity resistance of the composite tubes was encouraging the braided tubes leaked very badly as soon as they began to strain. In this connection it was interesting to note that all untested tubes were dark green in colour whereas those which had been strained had a milky white appearance, the change being particularly noticeable in the braided tubes which may not have been braided at the correct helical angle for pressure vessels.

Composite tubes 8 in. dia. with 0.20 in. wall thickness had often been subjected to 2300 lb/sq.in. internal hydraulic pressure when end closures were being tested and some had been taken up to their test pressure of 1600 lb/sq.in. seven or eight times without sign of trouble.

It was stated that a design figure of 70,000 lb/sq.in. hoop stress was being adopted for composite wound tubes and that the wall thickness of the 8 in. motors being made would be reduced to 0.125 in.

Our hosts were confident that they could produce composite wound glass tubes developing a hoop stress of 80,000 to 100,000 lb/sq.in. with a Youngs Modulus in the hoop direction of 10×10^6 and when this figure was questioned they suggested that it might be possible to achieve this Modulus figure in the axial direction as well. We made it clear that we thought these figures bordered on the miraculous and that we looked forward to the day when fibres of such stiffness became available in the form of continuous filaments.

Considerable work has been done with strain gauges on glass laminates and consistent results are said to be obtained. The strain gauges used are supplied by the Baldwin Locomotive Works, Philadelphia, under designation Type A1 SR 4, Resistance 119.6 $\omega \pm 0.2\,\omega$, Gauge Factor 2.02 ± 1%, and are fixed to the specimen with "Duco" cement.

5.6 Economics

The Goodyear Aircraft Corpn. were not as optimistic as A.B.L. on the cost of production of glass wound motors, although they thought that the braiding technique might well prove the cheapest form of production for J.A.T.O. projects. They thought the use of non-strategic materials was the most important argument in favour of reinforced plastic motors and hoped the cost of raw materials could be gradually reduced.

5.7 Matters of general interest

(a) The G.A.C. are now tooled up to produce 400 steel Terrier boost motors per month. Automatic submerged arc welding is used for axial and circumferential welds and very accurate jigging and inspection rigs are used to ensure correct nozzle alignment.

(b) Magnesium alloy tubes

A most interesting method for re-orienting the relative axial and hoop strength of solid drawn ZK60A magnesium alloy tubes has been developed and is in use. Tubes of 5 in. dia. received with ultimate axial and hoop strengths of 42,000 and 20,000 lb/sq.in. respectively are constrained axially in a special tool at a pressure of about 1000 lb/sq.in. while they are subjected to gradually increasing internal hydraulic pressure. When treatment is complete their external diameter has been increased by half an inch with a proportional decrease in length while their

ultimate axial and hoop strengths have been changed to 24,000 and 40,000 lb/sq.in. respectively.

(c) Manufacture of steel nozzles

A steel nozzle of about Terrier size was seen, the entry and throat of which were forged in 1% chrome, 0.25% molybdenum steel; a thin spun mild steel exit cone was welded to it. The internal finish was very good and it was said that owing to low wastage of material the total cost compared very favourably with all other methods of manufacture.

5.8 Conclusions

The representatives we talked to at G.A.C. were not so sanguine as A.B.L. about the possibility of producing reinforced plastic motors more cheaply than in other materials but they thought their composite cloth and roving tube could be made into an extremely efficient motor. They pointed out that they had already shown a weight saving of 30% and an increase in overall Specific Impulse from 137 to 145 compared with the steel motor ordered by A.B.L. for evaluation tests, and hoped to do considerably better. The two machines required for their manufacture are simple and cheap and do not require skilled labour to operate or set them.

Because we did not see the braiding machine in operation, it is difficult to assess the possibilities of this method of manufacture but considerable enthusiasm exists and no doubt the quality of the product will increase as experience is gained.

6 General Conclusions

At all the firms visited there is very considerable enthusiasm and confidence in the future of reinforced plastics for rocket motor cases and this confidence was particularly in evidence at the Allegany Ballistics Laboratory who now intend going ahead and having a complete plastic motor produced in quantity.

No serious thought seems to have been given to manufacturing a complete plastic missile but this may well follow when the evaluation of reinforced plastic tubes in bending and torsion has been completed.

The helically wound motor, made by M.W. Kellogg Co. and Young Development Laboratories using glass rovings and a 65/35 mixture of Epon resins Nos. 828 and 562 are the most efficient pressure vessels being made at present. With a glass to resin ratio of 75 to 25, S.G. about 2.0, they develop ultimate hoop stresses of around 75,000 lb/sq.in.; the mouldings are virtually non-porous up to hoop stresses of 60,000 lb/sq.in., though their strength in bending is not high enough to sustain flight loads. Their loss in strength at elevated temperature and their behaviour under shock loading conditions are not yet known.

The helical winding machines developed by Mr. Young and used at M.W. Kelloggs and his own works lay on rovings very much more accurately than the R.A.E. machine but otherwise the techniques are very similar.

The contract with the Goodyear Aircraft Corpn. was placed to investigate cheaper methods of manufacture, but it appears that the polyester impregnated composite motor, wound with unidirectional glass cloth and circumferential rovings, may well prove a keen competitor in structural efficiency with the helically wound type, especially as its bending properties could be improved by moving the axially unidirectional

cloth nearer the outside of the tube wall. Braided motors with integral nozzles can be manufactured very cheaply but it is doubtful if their efficiency can be got high enough for anything but J.A.T.O. application.

The 16 in. dia. all plastic disposable boost motors made by Young Development Laboratories have been fired successfully but they were so heavy that it can be said that no efficient plastic motor of more than 8 in. dia. has been made in U.S. to date.

The treatment of glass is important in two ways in that good "wetting" by the resin is essential if low porosity and high bending strength are required, but existing treatments which achieve this so damage the glass fibres during processing that the highest hoop stresses cannot be realised.

Generally speaking the attitude to the large strains associated with glass reinforced structures was that they must be accepted and accomodated by the weapon designer.

Nozzles are being wound in glass tape and moulded at medium pressure in chopped glass rovings using various impregnating resins but although burning times are only 4 secs. it is necessary to fit them all with carbon or steel throat inserts. A high pressure tool has just been completed for glass-phenolic mouldings but as a result of our visit asbestos-phenolic moulding flock will be used as well.

Plastic end closures using glass cloth or rovings or asbestos fibres with various resins are being developed energetically. They are usually secured by segmented shear rings located in grooves machined in light alloy sleeves which are secured to the ends of the tube by glued scarf joints.

The glued scarf joint method of effecting end closure is being used by all the firms visited and is highly efficient for tubes up to 8 in. dia. and probably up to 10 in. dia. Shear stresses as high as three times those developed by normal lap joints, using the same materials and adhesive, have been recorded and this is probably due to the internal pressure delaying the delamination in the plastic which always occurs in a good plastic to metal glued joint.

Generally speaking U.S. thought and development on reinforced plastic motors and components seem to be running remarkably parallel with the work in this country. They are using resins not yet available in the U.K. and have made tubes with higher hoop strengths than we have at the R.A.E., but there is no doubt that their development of plastic nozzles is some way behind. Information was freely exchanged on all subjects and there is no doubt that the visit was of great mutual benefit.

7 Recommendations

7.1 In order to investigate the effect of extreme accuracy in winding, tubes should be made on the R.A.E. machine using the standard U.S. mixture of Epon resins and chrome treated rovings.

7.2 Although U.S. appear convinced that the optimum helical winding angle for pressure vessels is 55° with the axis, an effort should be made to establish this experimentally and to evaluate the effect of resin content upon it.

7.3 The main differences between Epon and polyester resins appear to be connected with the capacity for wetting or adhering to glass and with their shrinkage on cure. Shrinkage values should be determined for all resins and made available to users. Epon resins should not be accepted as the cure of all evils and evaluation of others, such as Bakelite polyester No. 17449, for manufacture of tubes, should be proceeded with.

7.4 Close touch should be kept with R.A.E. Chemistry Dept's work on glass finishes and efforts made to persuade glass manufacturers to produce rovings suitably treated at the filament drawing stage.

7.5 The scarf type end closure attachment should be thoroughly investigated and scaled up by making short length specimens for hydraulic test. Prior to this, standard aluminium to glass glued lap joints, using Epon No.VI adhesive, should be tested with and without compressive forces of up to 2,000 lb/sq.in. acting normal to the glued surfaces while they are being pulled.

7.6 A hydraulic testing machine capable of loading tubes at a rate comparable to that on firing would be most useful and if available to all those engaged in the production of plastic motors it would pay for itself in a very short time.

7.7 We were much impressed by the close liaison maintained between A.B.L. and their contractors which effectively prevented any duplication of effort and kept everybody's interest alive.

References

No.	Author	Title, etc.
1	M.W. Kellogg	Filament wound plastic rocket structures S.P.D.348. October 1952
2	Young Development Laboratories	Description of winding machine and method of gear selection. R.316-100. April 1952

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APPENDIX I

Glued scarf joints for end closure attachment

Table I and sketches at Fig.4, which were abstracted from a Goodyear Report, show the shear strengths developed by various adhesives when strips, of widths W, cut from 8 in. dia. tubes, were pulled in a tensile testing machine.

For the joint now standardised for end closures the aluminium sleeve is dipped in chromic acid, and glass and metal surfaces degreased with M.E.K. The adhesive, six parts of Epon No.VI mixed with one part of accelerator A, giving a pot life of about one hour, is spread on both surfaces, and after an open assembly time of 15 minutes the parts are pressed firmly together and the assembly is cured at 200°F(93°C) for four hours. The lands of 0.040 in. at each end of the joint are designed to control the glue line thickness at 0.010 in ± 0.005 in. and it is said that a glass cloth or cotton gauze filler in the glue line tends to make the stick more reliable.

The best scarf angle is said to be about 2° but it is felt this must be closely related to wall thickness and the relative stiffness of the materials used, because it may well affect the effective length of the joint. For the same reason and to avoid hoop stress concentrations in the glass at the inner end of the metal sleeve it is suggested that it may be desirable to dispense with the 0.040 land specified at this point and rely on a fabric filler to control glue line thickness.

Table I

Shear strengths developed by Scarf Joints (Abstracted from Goodyear Report No.GER 5313)

	Material	Joint	Cement	Dimension Joint W	Breaking Load lb. In.	Load In.	Shear lb/sq.in.	
A-16	Al. & Fiberglass	B	Epon VI	0.700	1320	1890	900	181 cloth laminated with
A-17	"	"	"	0.700	1440	2060	980	Epon 828
A-18	"	"	"	"	1590	2270	1080	
A-19	"	"	"	"	1420	2030	970	
A-20	"	"	"	"	1540	2200	1050	(980 p.s.i. av.)
A-21	"	"	"	"	1670	2385	1148	143 cloth laminated with
A-22	"	"	"	"	1580	2260	1075	Selectron 5003
A-23	"	"	"	"	1260	1800	860	
A-24	"	"	"	"	1510	2160	1030	
A-25	"	"	"	"	1520	2170	1035	(1029 psi.)
A-26	Al. Fiberglass	B	Epon VI	0.700	1400	2000	952	Aluminium treated with
A-27	"	"	"	"	1410	2020	961	chrome acid
A-28	"	"	"	"	1420	2030	967	
A-29	"	"	"	"	1230	1760	839	
A-30	"	"	"	"	1535	2195	1045	(953 psi.)
P-11	Fiberglass to	C	Paraplex	0.754	1100	1476	975	50% P43, 50% P18 cement
P-12	Fiberglass	"	"	0.743	1320	1780	1200	
P-13	"	"	"	0.743	1310	1765	1112	
P-14	"	"	"	0.752	1290	1720	1155	
P-15	"	"	"	0.756	1220	1615	1051	(1099 psi.)
A-1	Al. Fiberglass	A	Epon VI	0.688	1160	1690	820	Curv. developed longitudinally
A-2	"	"	"	0.688	1150	1670	809	
A-3	"	"	"	0.688	1150	1670	809	
A-4	"	"	"	0.688	1140	1660	805	
A-5	"	"	"	0.688	1150	1670	809	(810 psi.)
A-6	"	D	"	0.750	1546	2055	912	
A-7	"	"	"	0.750	1580	2100	935	
A-8	"	"	"	0.750	1670	2225	1000	
A-9	"	"	"	0.750	1590	2120	945	
A-10	"	"	"	0.750	1570	2095	932	(945 psi.)
A-11	Al. Fiberglass	B	Epon VI	0.700	400	571	272	Poor bond separated
A-12	"	"	"	0.700	528	755	360	before start of test
A-13	"	"	"	0.700	494	705	346	
A-15	"	"	"	0.700	774	541	258	(309 psi.)

Table I (Contd.)

	Material	Joint	Cement	Dimension Joint W	Breaking Load lb. In.	Load In.	Shear lb/sq.in.	
S-1	Fiberglass to	A	Selectron 5096	0.752	1900	2530	1120	143-114 cloth laminated
S-2	Fiberglass	"	"	0.753	1655	2170	962	with selectron 5003
S-3	"	"	"	0.752	1540	2050	910	
S-4	"	"	"	0.753	1580	2100	930	
S-5	"	"	"	0.750	1630	2175	967	(978 psi.)
P-1	Fiberglass to	A	Paraplex	0.755	1890	2500	1103	50% P43, 50% P13 cement
P-2	Fiberglass	"	"	0.752	1840	2450	1085	
P-3	"	"	"	0.754	1810	2400	1060	
P-4	"	"	"	0.755	1855	2460	1085	
P-5	"	"	"	0.755	1900	2520	1113	(1089 psi.)
E-1	"	"	Epon VI	0.654	1530	2340	1195	
E-2	"	"	"	0.753	1630	2160	970	
E-3	"	"	"	0.753	1560	2020	912	
E-4	"	"	"	0.751	1600	2130	945	
E-5	"	"	"	0.752	1635	2180	964	(997 psi.)
P-6	Fiberglass to	B	Paraplex	0.756	1990	2630	1157	50% P43, 50% P13 cement
P-7	Fiberglass	"	"	0.755	2080	2760	1221	
P-8	"	"	"	0.753	2000	2660	1178	
P-9	"	"	"	0.754	2020	2180	1185	
P-10	"	"	"	0.754	2140	2840	1271	(1202 psi.)

APPENDIX II

List of U.S. Reports on Plastic Rocket Motor development

Goodyear Aircraft Corporation, Akron 15, Ohio, Contract NOrd 10738, Research and Development of Inert Components for Rocket Cases, Summary of Progress, 20 September 1952 to 20 March 1953, 21 April 1953, GER-5313.

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Goodyear Aircraft Corporation, Akron 15, Ohio, Contract NOrd 10738, Summary Report, Development of Light Alloy and Plastic Rocket Cases, GER-2579, 18 May 1951.

Young Development Laboratories, Inc., P.O. Box A, Rocky Hill, New Jersey, Contract NOrd 10431 Sub-Contract #7, Engineering Report No. R1293-100, Part B, A Study of Materials for Use in Fiberglass Filament-Wound Structures, October 30, 1953.

Young Development Laboratories, Inc., P.O. Box A, Rocky Hill, New Jersey, Engineering Report No. R890-100, Glass Plastic Filament-Wound Nozzles, November 24 1952, for Hercules Powder Co., Purchase Order ABL 24911.

Young Development Laboratories, Inc., P.O. Box A, Rocky Hill, New Jersey, Engineering Report No. R969-100, A Study of Materials for Use in Fiberglass Filament-Wound Structures, for Hercules Powder Co., ABL, Cumberland, Md., November 28 1952.

Young Development Laboratories' Report No. R316-100, Description of Winding Machine and Gear Selection, 20 April 1952 (a revised version will be available before the end of 1954).

The Glenn L. Martin Company, Baltimore 3, Maryland, Interim Status Report, Nike and Terrier Disposable Boosters, Engineering Report No.5088, May 1 1952, Contract DA-36-034-ORD-93.

The Glenn L. Martin Company, Baltimore 3, Maryland, Quarterly Progress Report Disposable and Consumable Boosters, Engineering Report No.5375, September 30 1952, Contract DA-36-034-ORD-93.

Fairchild Engine & Airplane Corporation, Fairchild Guided Missiles Division, Wyandanch, Long Island, New York, Ordnance Project TU2-2019 B, Design and Development of a Glass Reinforced Plastic Motor for JATO 14-DS-1000, T56, Summary of Progress for September 1953, Ordnance Contract DAI-30-069-501-ORD(P)-1028, 20 October 1953, Report No. 35M-945.

Fairchild Engine & Airplane Corporation, Fairchild Guided Missiles Division, Wyandanch, Long Island, New York, Ordnance Project TU2-2019 B, Design and Development of a Glass Reinforced Plastic Motor for JATO (14DS-1000, MK 4, Mod.2) Summary of Progress for May 1953, Ordnance Contract DAI-30-069-501-ORD(P)-1028, 10 June 1953, Report No. 35M-922.

B.J.S.M. have been asked to send copies of all the above reports to Chemistry Dept., R.A.E.

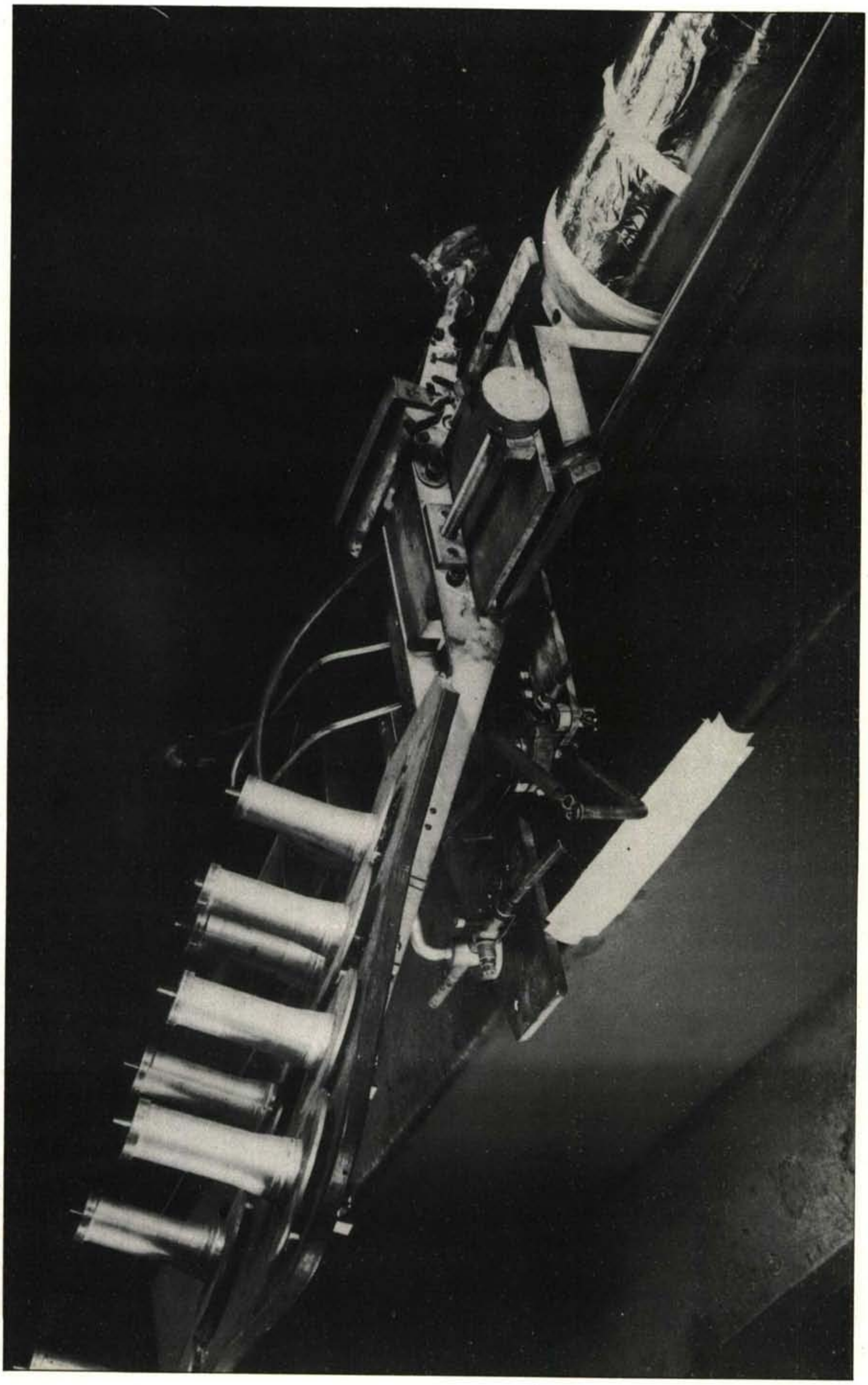


FIG.1. GENERAL ARRANGEMENT OF KELLOGG TUBE WINDING MACHINE

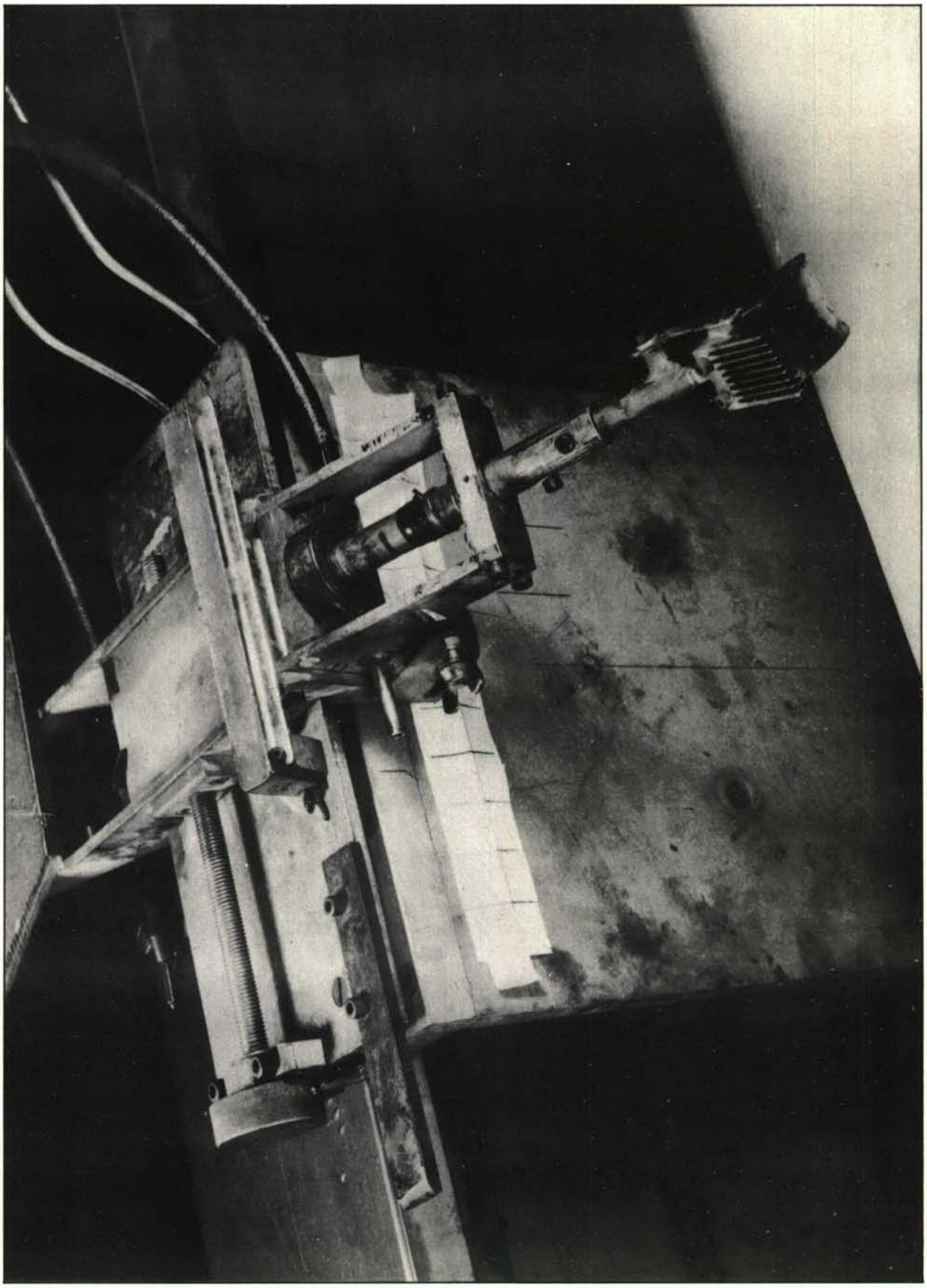


FIG.2. COMB AND TONGUE OF KELLOGG TUBE WINDING MACHINE

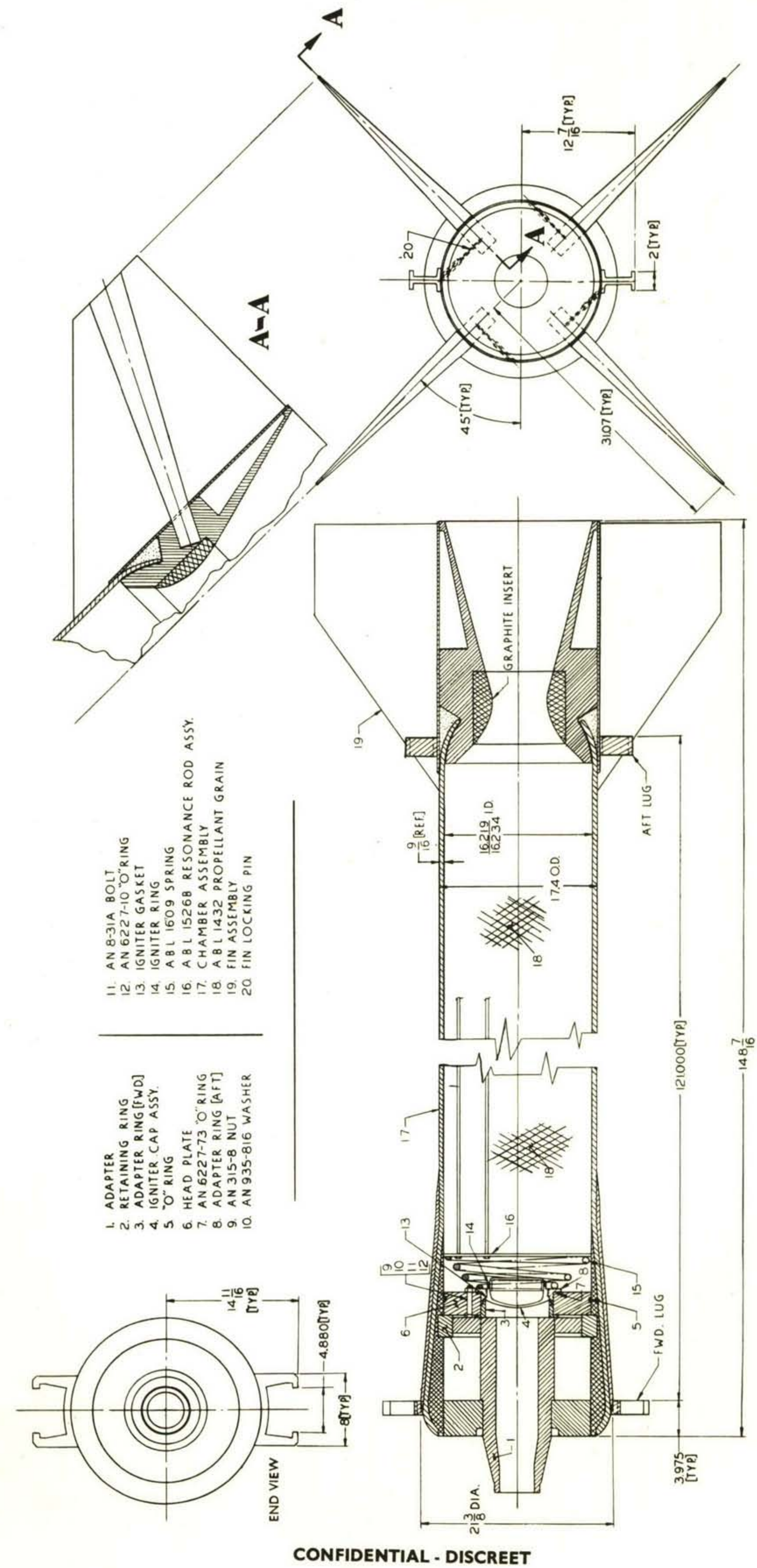
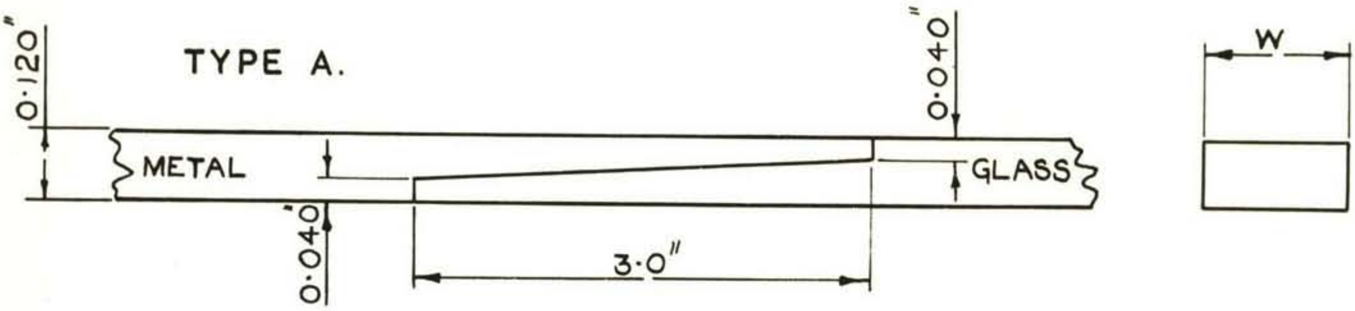
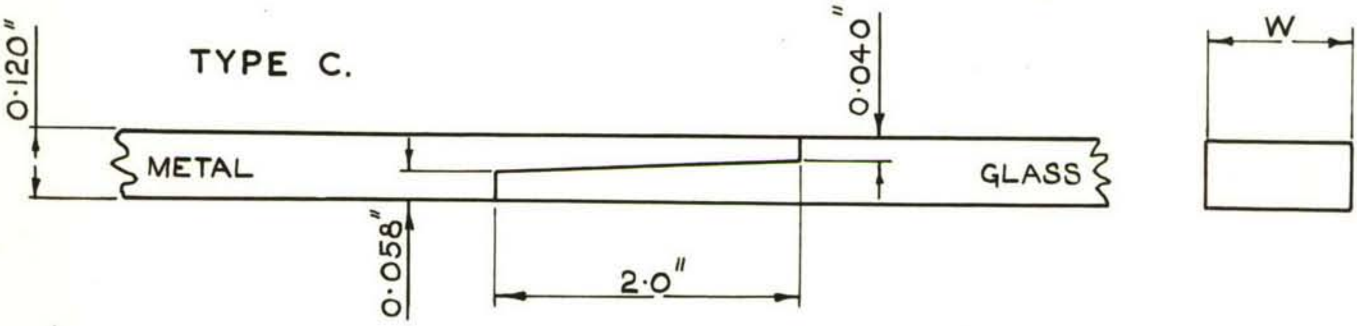


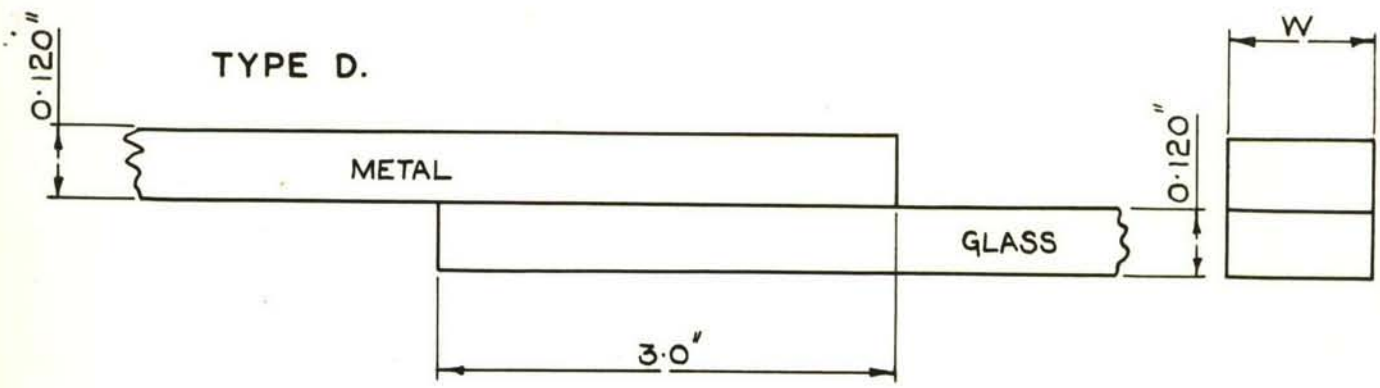
FIG.3. DISPOSABLE TERRIER BOOST MOTOR



TYPE B.

AS ABOVE BUT WITH 128 GLASS CLOTH IN GLUE LINE.





N.B. DIAGRAMMATIC ONLY;
NOT TO SCALE.

FIG. 4. GOODYEAR AIRCRAFT CORPN. U.S.A.
SCARF JOINTS.

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Royal Aircraft Establishment Technical Note Chem.1218 — 621.455.002.3: 679.5: 677.51/2
1954.2
Lloyd, T.

REPORT ON VISITS WITH MR. A.G.P. VAUGHAN AND MR. J. HARDWICK OF IMPERIAL CHEMICAL INDUSTRIES LTD. TO A NUMBER OF U.S. FIRMS ENGAGED IN THE DEVELOPMENT OF REINFORCED PLASTIC ROCKET MOTOR BODIES
23RD NOVEMBER TO 8TH DECEMBER 1953

The development of reinforced plastic rocket motors in the United States has reached very much the same stage as it has in this country.

Motors are being helically wound with glass rovings and Epon resins which develop hoop stresses of 80,000 lb/sq.in. on a specific gravity of 2.0.

The attachment of end closures has been found the most difficult problem to overcome but a highly efficient method of scarf jointing metal sleeves to

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Glass reinforced plastics are being used for end closures, nozzles and tail pipes but there is now a tendency to switch to the asbestos/phenolic materials which are preferred in this country

Dr. L.G. Bonner of the Allegany Ballistics Laboratory summed up the opinion of all those we met by saying there was "very considerable confidence in the future of reinforced plastics for the manufacture of rocket motors" and that the time had come to go ahead and produce an all-plastic motor, possibly in large numbers.

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DETACHABLE ABSTRACT CARDS

The abstract cards detached from
this document are located as follows:-

1 ____________________ 2 ____________________

3 ____________________ 4 ____________________

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